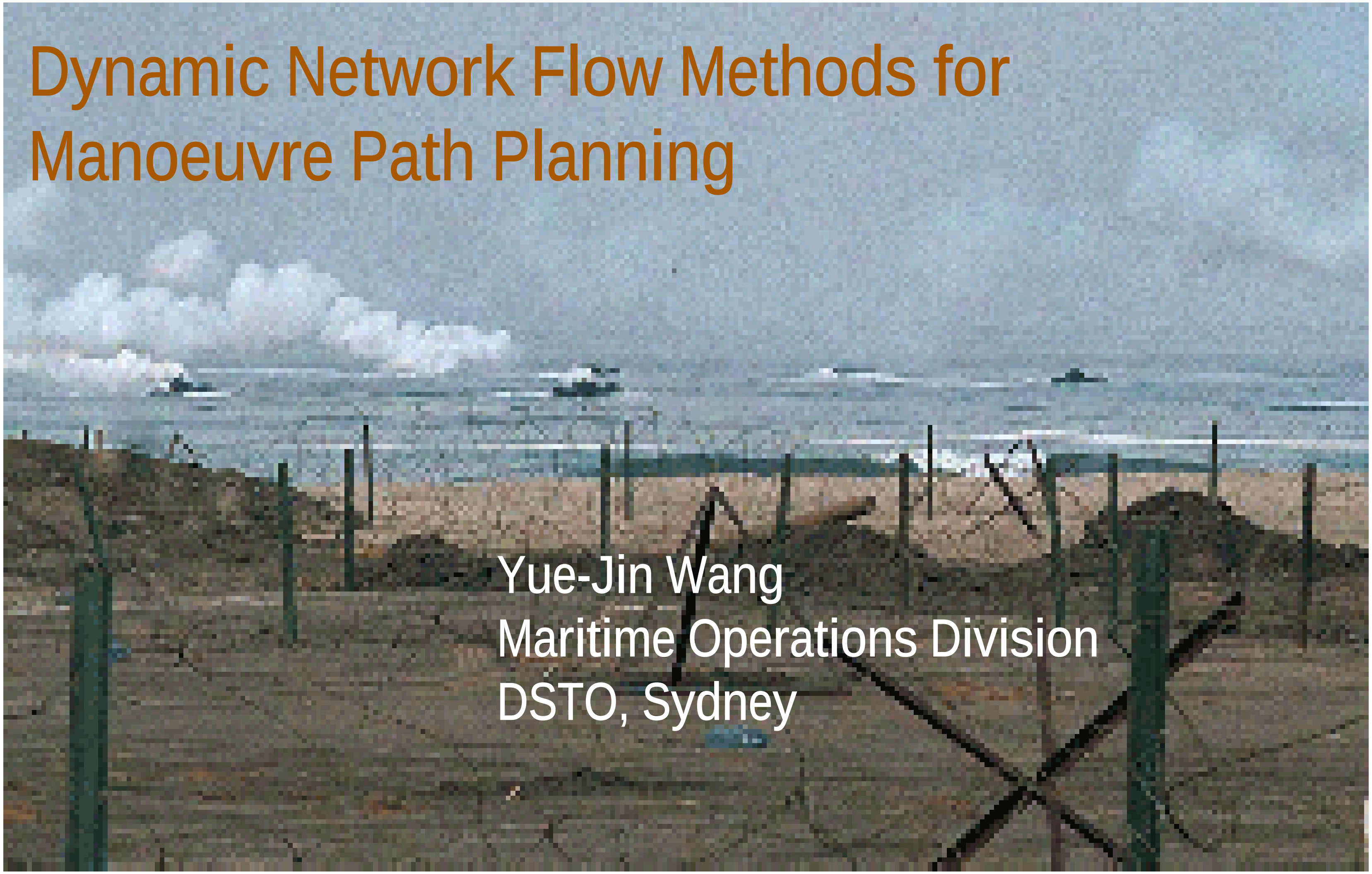
Dynamic Network Flow Methods for Manoeuvre Path Planning



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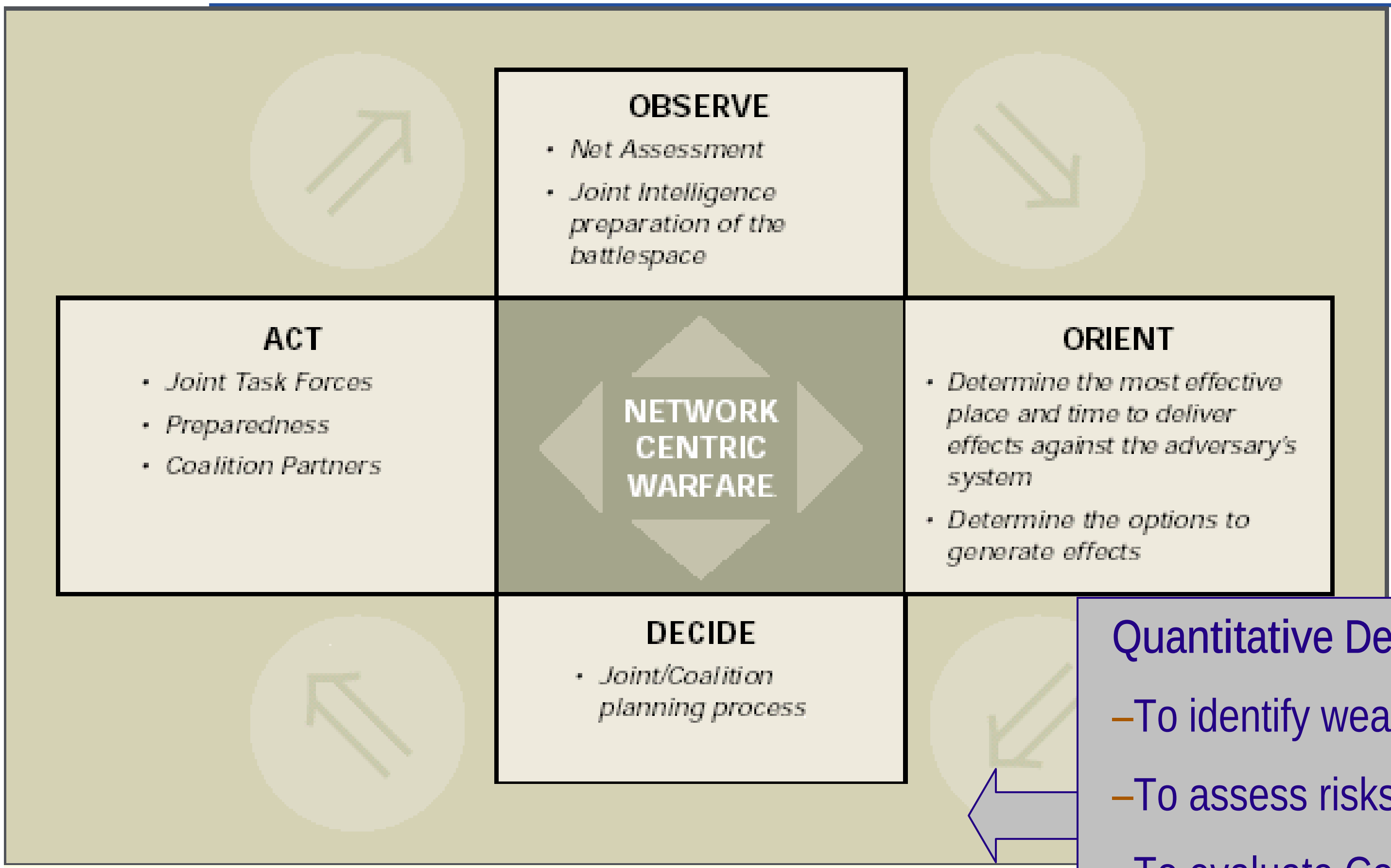
Introduction

- Objectives
  - To explore the application of Network Flow modelling to quantifying manoeuvre space
- Scope
  - Manoeuvre Operations
  - Dynamic Network Flow Modelling for Manoeuvre Path Planning
  - Risk Modelling
  - Mine Threat Example
  - Summary

Manoeuvre Operations - OODA Loop



Quantitative Decision-aid is needed:

–To identify weaknesses/strengths

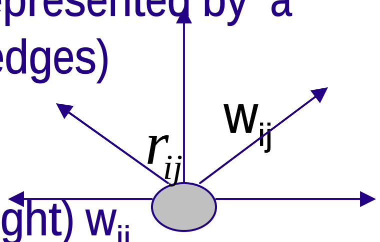
–To assess risks

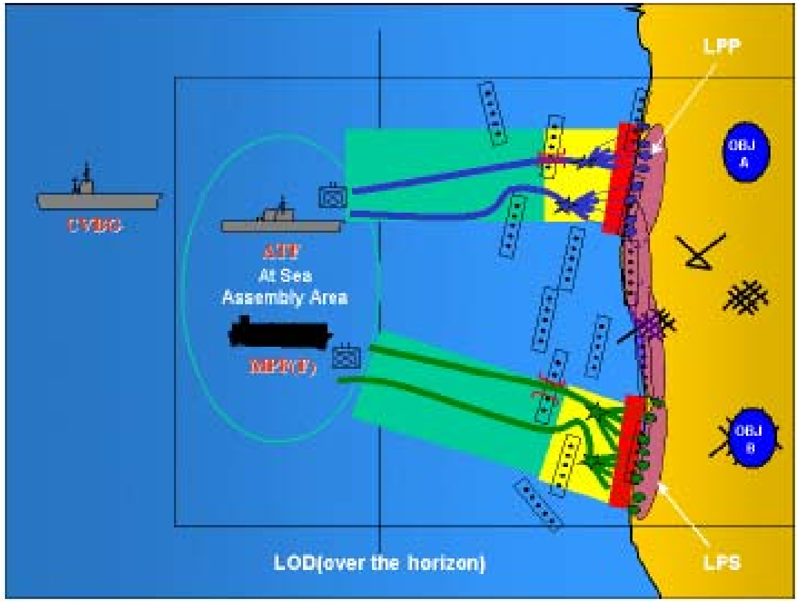
–To evaluate Course of Actions(COAs) against criteria

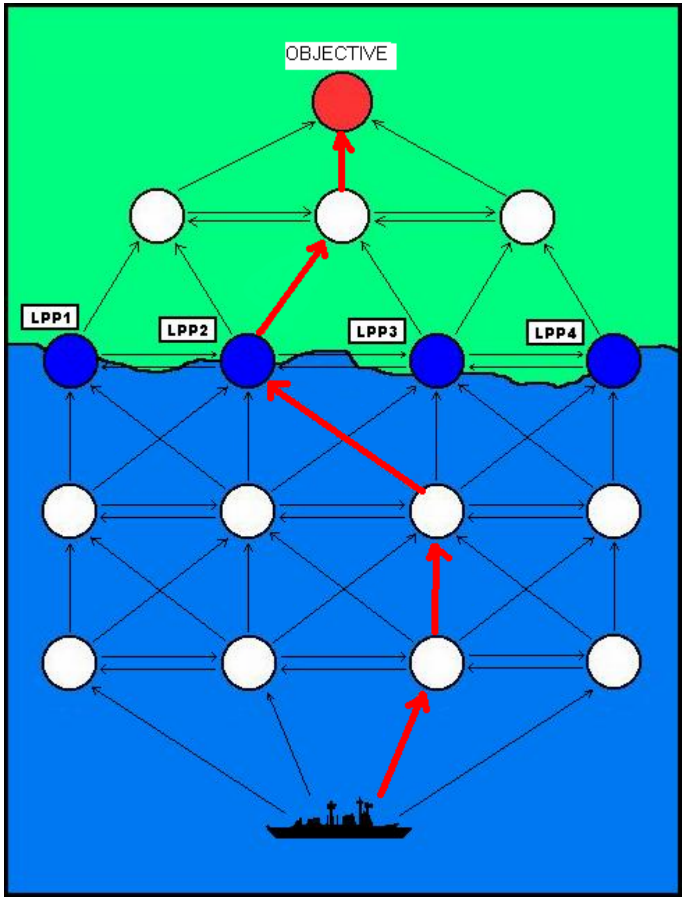
–To select the optimal COAs

Dynamic Network Flow Model for Manoeuvre Path Planning

- Manoeuvre space represented by a Grid Graph (nodes,edges)
- Risk (cost) r_{ij}
- Travelling Time (weight) w_{ij}







Multi-objectives Optimisation

- Path Risk $\sum_{i=1}^{P} r_{ij}$

- Path Length $\sum_{i=1}^{p} w_{ij}$
- (Time-to-Goal)

Modelling

(1) Min linear combination of time and risk

$$\alpha \sum_{k=1}^{p} r_{i_{k-1} i_k} + (1-\alpha) \sum_{k=1}^{p} w_{i_{k-1} i_k}$$

(2) Min path length with fixed constraint on risk

$$\sum_{k=1}^{p} w_{i_{k-1} i_k}$$

S.t. $r_{i_{k-1} i_k} \leq R$

Modelling (continue)

- Min risk with fixed constraint on path length

$$\text{min.} \quad \sum_{k=1}^{p} r_{i_{k-1} i_k}$$

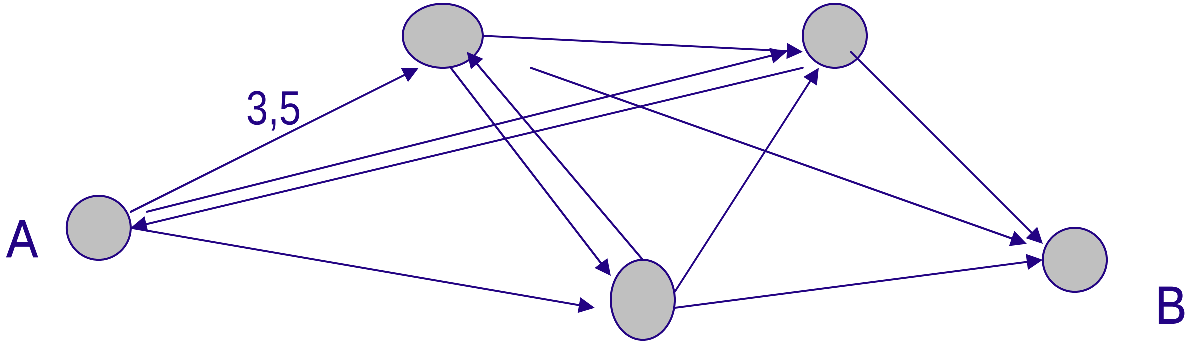
$$\text{s.t.} \quad \sum_{k=1}^{p} w_{i_{k-1} i_k} \le W_0$$

Weight Constrained Shortest Path Problem (WCSSP)

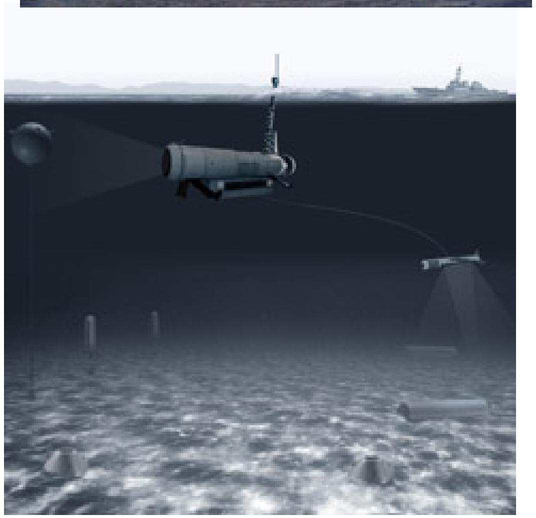
- Way-points and multiple goals

Algorithms for WCSPP

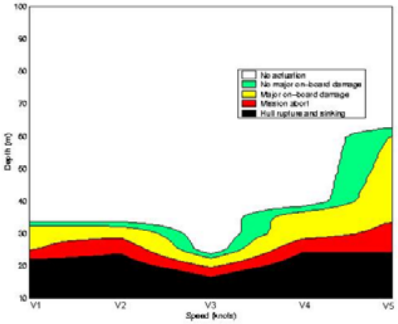
- Label-setting algorithms based on dynamic programming methods
- Scaling algorithms, and
- Algorithms based on the Lagrangean relaxation approach.



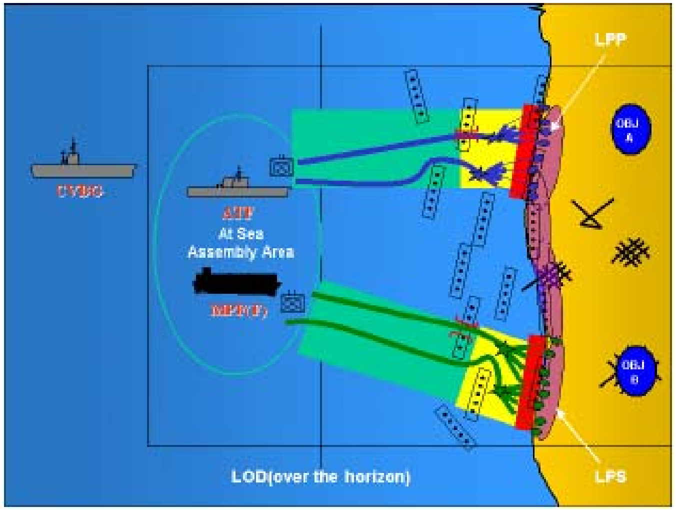
Risk Modelling



- A responsive and reliable Intelligence Surveillance and Reconnaissance (ISR) system is a prerequisite for risk modelling
- Dynamic manoeuvre space modelling requires dynamic ISR tasking,integration and dissemination.
- Risk modelling involves incorporating spatial and time-dependant uncertainties



An Example of Path Planning Through Mine Fields



Perimeter Minefield
(50 nautical miles from shore, and in 40 to 200 ft of water. moored contact mines and big bottom influence mines)

Main Minefield
(7 to 9 nautical miles from shore, and,again, in 40 to 200 ft of water. moored contact mines and bottom influence mines)

Very Shallow Water Minefield
(located 0.5 nautical miles from the surf zone (SZ). small moored contact mines, Manta bottom influence mines.

Beach Barrier
The final barrier covers the SZ (10 to 0 ft) and the craft landing zone (CLZ) (high-water mark (HWM) to the beach exit zone (BEZ)). hardwood logs, telephone poles, or railroad rails driven into the offshore bar and angled seaward

Moored contact mines

Beach Barrier

WCSPP modelling for mine threat

- Point Risk: $$r(x) = 1 - \prod_{i=1}^{N} (1 - r_i(x))$$

  $r_i(x)$ = probability of getting killed by the ith mine at point x

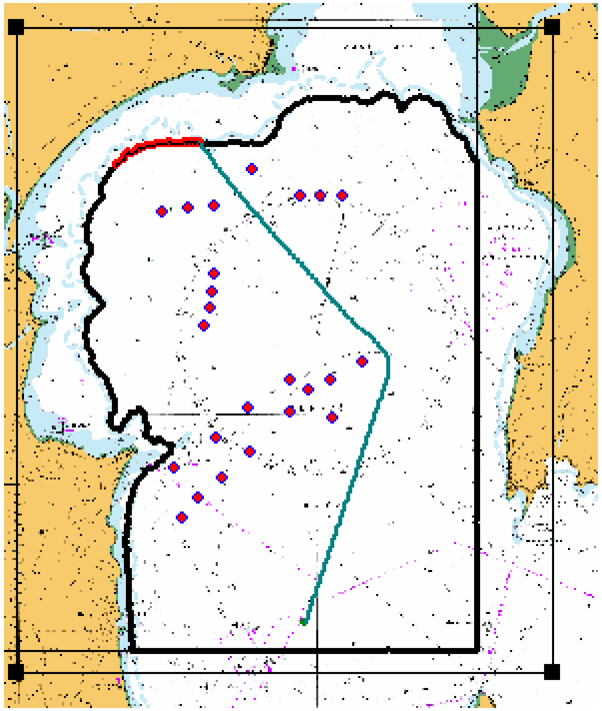
- Path Risk ($P=\{x_1,x_2,..x_p\}$) $$r(P) = 1 - \prod_{j=1}^{P} (1 - r(x_j))$$

- WCSS Model:

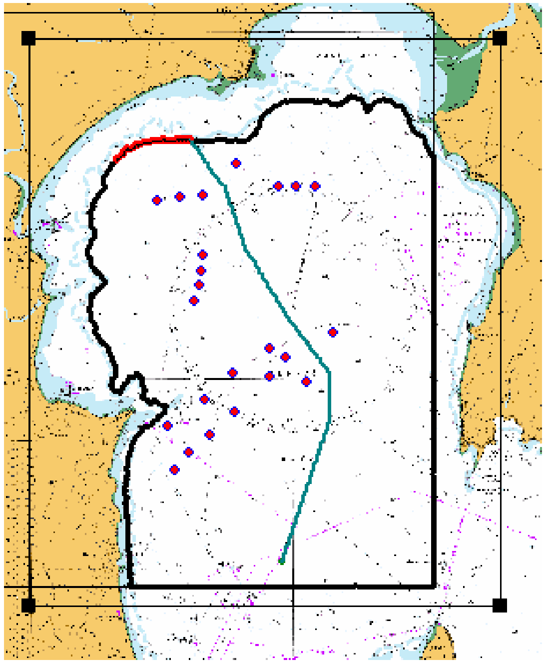
  minimise $r(P)$

  with constraints $\sum_{k=1}^{p} w_{i_{k-1} i_k} \le W_0$

Simulation of Alternate Paths



- Path total weight = 10.9927
- Path total cost = 57%
-



- **Path total weight = 10.4832**
- **Path total cost = 8.3%**

Summary

- Littoral domain is described with a grid directed graph
- Maritime manoeuvre operations are quantitatively formulated as a Weight Constrained Shortest Path Problem with the solution providing a command decision-aid tool
- A mine threat example is presented
- Further work include
  - To expand the scope to cover land-based manoeuvre
  - To include air and submarine threat modelling